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Mycelium Material Study

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Contents

Abstract

This study aims to explore mushroom mycelium as a potential composite material for construction and manufacturing applications. By inoculating a cellulose-rich waste material substrate (such as straw, sawdust, or grain hulls) with mushroom spawn, material can be "grown" and formed. The spawn, in this case from the Reishi mushroom, grows onto the substrate and forms mycelium, the root structure of the organisms whose fruits are mushrooms. This mixture, once formed and cured, is a light, organic material which can be formed similarly to some thermoplastics and foams. The current study investigates the effects of different substrates and different mesh-like support materials on the strength and tactile qualities of the material. Finally, to determine the level of achievable detail and complexity, an investigation was made into a few simple and complex forms using plaster cast molds. Findings suggest that the best substrate to use with Reishi spawn is plywood or a mixture of plywood and hardwood sawdust with coffee grounds added. The process took 2 weeks in the inoculation stage and another 11 days for final colonization on the support material. Metal support materials, such as hardware cloth and poultry netting, were very strong. However, the mycelium on these swatches crumbled easily from handling because the holes in the material are large and colonization was less uniform than on support materials with small meshes, like fabric and screening. The preliminary investigation into plaster cast molding is incomplete, as growth did not proceed as expected, though so far it offers some insight into mycelium's growth patterns.

Illustration 1: Creating bags of substrate

Introduction

Mycelium are the vegetative part of fungi and are composed of thin hyphae, the root-like structures which allow the fungus to absorb nutrients from its substrate. It has strong binding properties and processes nutrients from wood, straw, hulls, corn cobs, nut shells, etc. by using enzymes to convert cellulose in the substrate into chitin, a strong compound found in crustacean exoskeletons. The chitin acts like an adhesive, bonding the substrate particles together. In his book, *Mycelium Running: How Mushrooms Can Help Save the World*, Paul Stamets explains that the substrate must be pasteurized in order to grow mycelium, as there are competing organisms in organic materials which need to be killed to give the mycelium a biological advantage. However, some bacteria are helpful to mycelial growth, so it is not advisable to fully sterilize the substrate. Fungi are available in two forms: as spawn on a substrate and as spores in a syringe. The spore syringes are notoriously difficult to cultivate, and as spawn is essentially mycelium already cultivated on a substrate, using this greatly simplifies the process of growing more mycelium.

A few forays into the world of mycelium material have already been made, aided by the publication of mushroom-growing information on the web and in Stamets' book. Each cultivator has their own preferred growing method and substrate, and therefore achieve different results. One prominent example is the company Ecovative, which makes packing and insulation materials from Oyster mushroom mycelium grown on local agricultural waste products. The material is particularly suited to these uses because it is fire, mold, and water resistant, insulating, non-toxic, and compostable, unlike many synthetic polymers used currently. Philip Ross, an artist and architect, has been exploring other possibilities for mycelium, designing chairs, a tea house, and other experimental forms. He often makes mycelium blocks and then combines them to form larger structures, allowing the blocks to grow together to secure, but he has also made more complex designs. He uses Reshi mushroom mycelium grown on sawdust, and has also been investigating the effects of pressure, gas exchange, and air filtration on the strength of the final product. He explains his process in his 2012 patent, which, among other things, describes how breaking mycelium into very small pieces and compressing into a mold gives the strongest end product (US Patent 20120135504 A1).

Others exploring this technology include Merjan tara Sisman and Brian Mcclellan (students who make chairs and pendant light fixtures), Ford Motor Company (who is teaming with Ecovative to replace plastic and foam car parts with mycelium material), Eric Klarenbeek (who makes artistic chairs, combining mycelium with 3D printed bioplastic to create complex forms), Shigeru Yamanaka (who filed the first patent in 1989 for using mycelium to bond fibers together into a fabric or paper), and Jonas Edvard (whose MYX lamp shade made of oyster mushrooms grown on hemp and linen grows mushrooms which can be eaten a few weeks after it is purchased).

Research Questions

- Which complex shapes and what level of detail are possible in the material?
- Which processes (besides casting in a mold) can be used to form the material?
- What other complementary materials can be successfully introduced as reinforcement in the material? How do different reinforcement materials change the properties of the end product?
- How viable is it to create a supportive structure solely out of mycelium and substrate, without other support material?
- How long will it take to make a strong material from mycelium?

Hypotheses

- Reishi spawn will grow best on hardwood shavings, as they have fewer added chemicals than plywood and are more similar to the logs on which Reishi mushrooms naturally grow.
- The addition of hydrogen peroxide will reduce contamination in our substrates.
- The addition of coffee grounds will help mycelium grow more quickly due to its high nitrogen content.
- Metal and other sturdy support materials will make a very strong material when combined with mycelium.

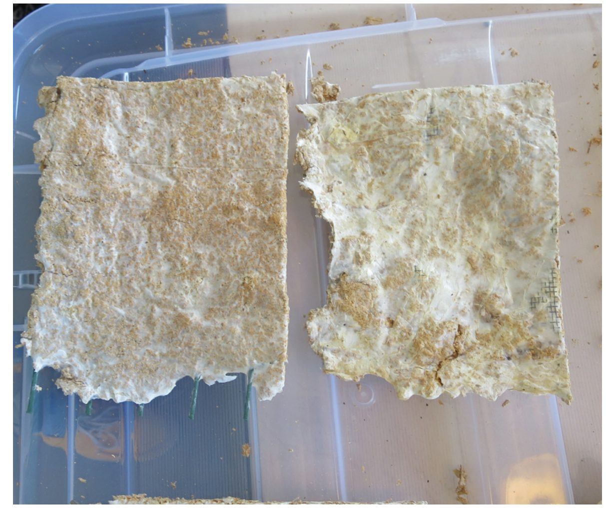


Illustration 2: Swatches of reinforced mycelium.

Method

Pre-colonized Reishi spawn was purchased and used to further colonize various mixtures of substrate in sterile and enclosed environments. Two forms were studied: plaster cast molded shapes and thin, flat swatches with different support materials embedded in the mycelium. After full colonization, the materials were cured and tested for flexural strength and other qualitative properties. The process took about 4 weeks to complete. For a complete list of materials used, see Appendix A.

Illustration 3: Prepared substrate mixtures

Preparing the substrate

Hardwood shavings, plywood sawdust, and also made a mixture of some of each were used as the basic substrate conditions. Each substrate was moistened until squeezing a handful allowed a few drops of water to escape (this is called "field capacity"). Coffee grounds were then added to some substrate, since some mushroom growers have found that the nitrogen in coffee acts as a sort of fertilizer and increases growth rates. A couple of bags of substrate had hydrogen peroxide added because it aids mycelial growth by discouraging competing fungi. Some growers use this method as an extra protection against contamination. In total, there were 8 substrate conditions:

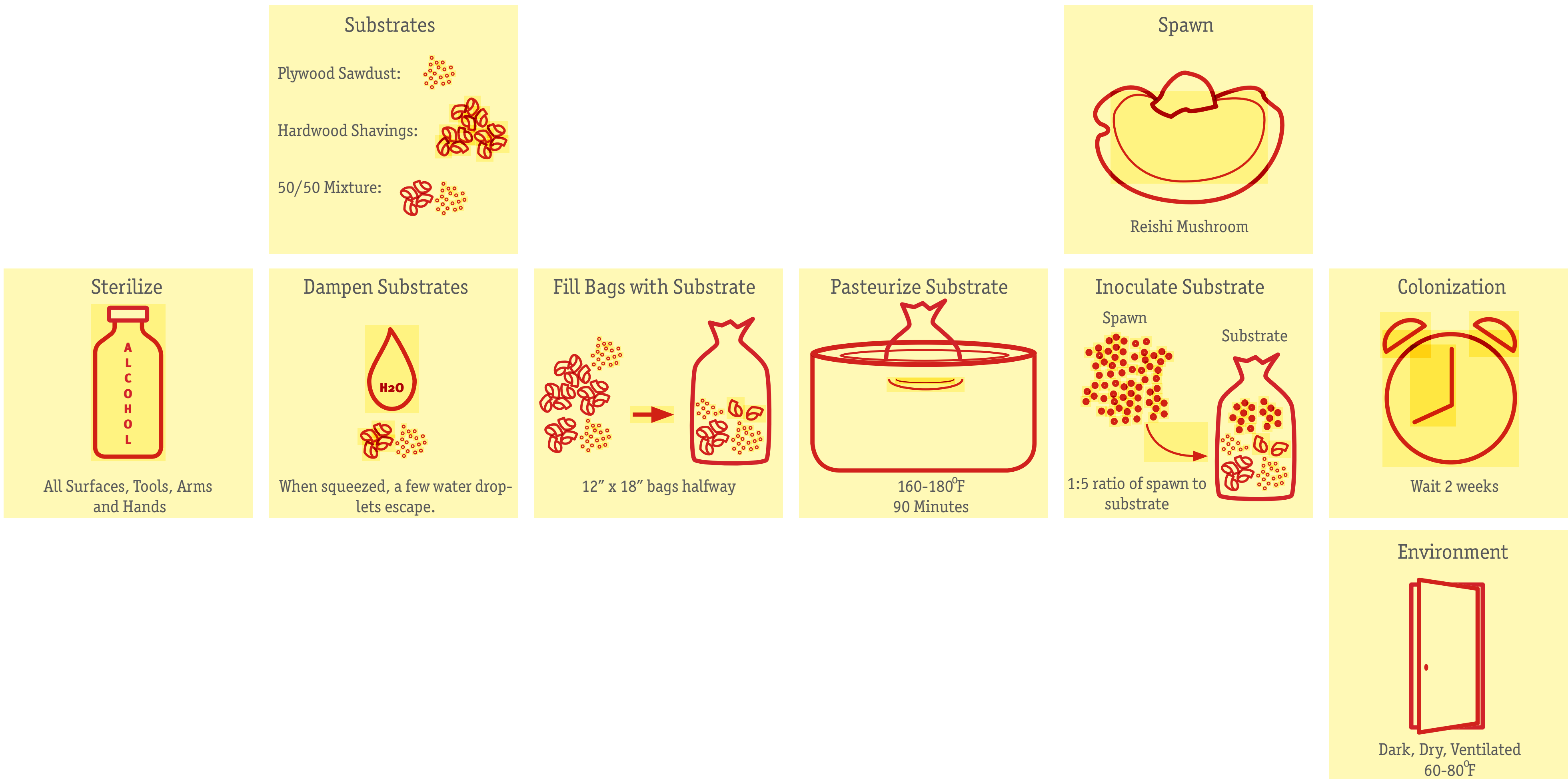
- Hardwood
- Plywood
- Mixed
- Hardwood + coffee (about a half cup to 4 cups of substrate)
- Plywood + coffee
- Mixed + coffee
- Plywood + Hydrogen Peroxide (about 4 tablespoons to 4 cups of substrate)
- Mixed + Hydrogen Peroxide

(We had a smaller amount of hardwood shavings than of plywood sawdust and thus were unable to do a trial with hardwood and hydrogen peroxide)

Each of these was put into a 12" x 18 " plastic bag and then pasteurized at 160 to 180 degrees Fahrenheit for 1 hour over a hot plate, keeping the bags raised from the bottom of the pot with a steamer basket. **The bags were then left to cool** to room temperature.

Illustration 4: Pasteurizing substrate

Inoculation and Colonization Flow Chart



Inoculating substrate with spawn

Once the bags of substrate were sterilized, they were inoculated with spawn at about a 1:5 ratio (by volume) of spawn to substrate and then resealed. During this process, it was very important to sterilize everything: the tabletop, our hands, the substrate bags, etc. so that no contamination could occur.

Note: The spawn comes as a large block of mycelium grown on some (unknown) substrate, so it must be broken into small pieces before mixing with the fresh substrate to ensure even distribution of spawn. Also note that the spawn will be completely white with mycelium on the exterior, but the interior may look to have less mycelium. This is another reason that mixing and breaking up the spawn is so important.

Illustration 5: Breaking up and measuring spawn

Illustration 6: Inoculating substrate with spawn

Colonization

It took 2 weeks for the spawn to colonize the substrate, as shown below. Once colonized, the bags were firm to the touch and felt much like the original spawn used to inoculate the substrate. As with the original spawn, when broken, the interior was less white than the exterior. After 2 weeks of colonization, they were ready for molding.

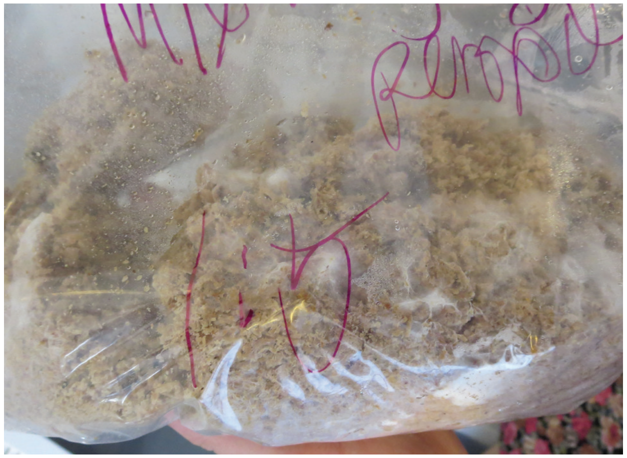


Illustration 7: Day 4 of Colonization

Illustration 8: Day 5 (note mycelium growth pattern)

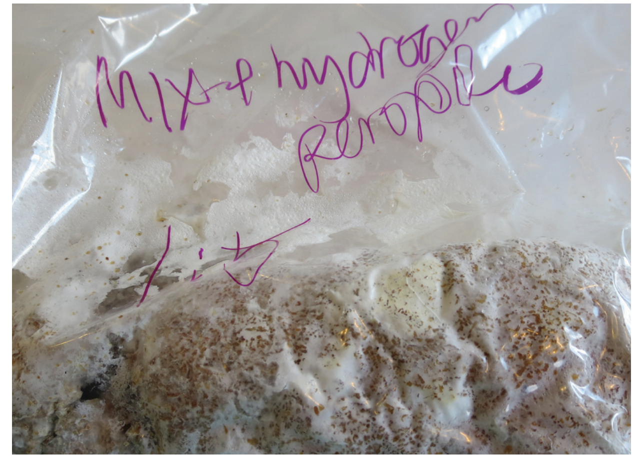


Illustration 9: Day 11

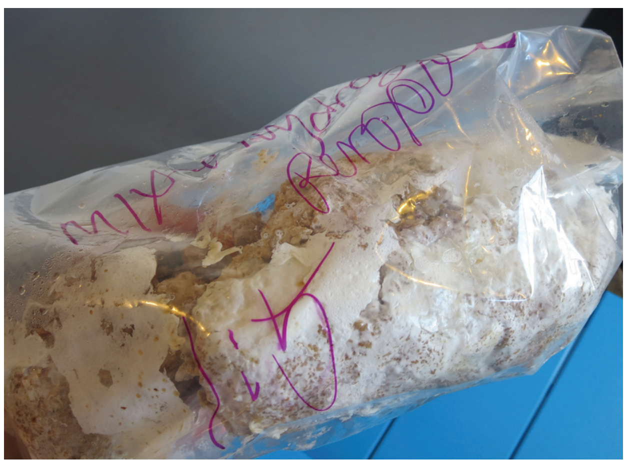


Illustration 10: Day 12

Illustration 11: Day 13

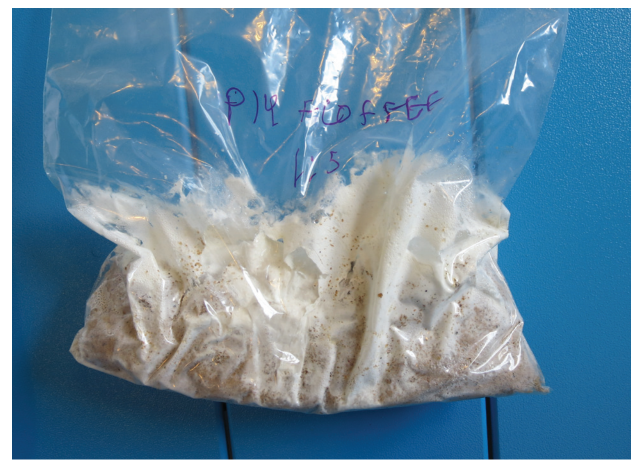


Illustration 12: Day 14

Molding colonized substrate (support swatches)

To investigate the reinforcing ability of various support materials (hardware cloth, poultry netting, burlap, nylon mesh, metal window screening, fiberglass window screening, and plastic garden fencing), the materials were integrated to swatches of mycelium material. Because there were 8 different substrate combinations, this resulted in a total of 56 swatches. Small rectangles (about 4x6 inches) of the support materials sandwiched between the colonized substrate side by side in a large clear (sterilized) trash bags, one for each substrate condition. We stored these 8 bags one on top of another, putting a large sheet of cardboard and a couple of bricks on top to compress the swatches and minimize light exposure.

Illustration 13: Support material swatches (not shown: window screening)

Illustration 14: Preparing swatches

Illustration 15: Bag sealed and labeled

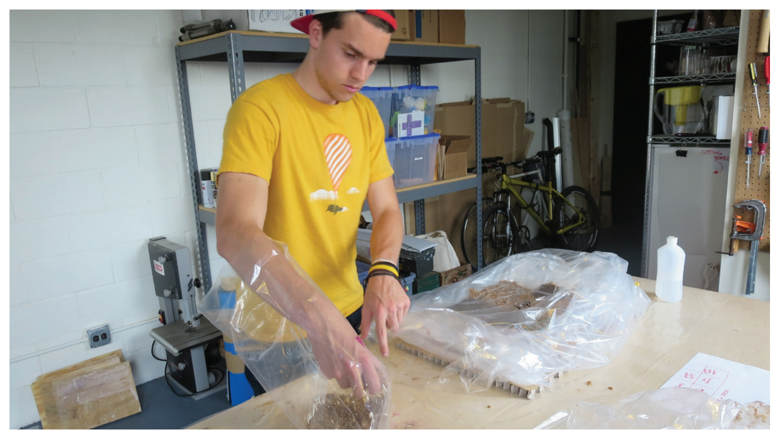


Illustration 16: Preparing swatches

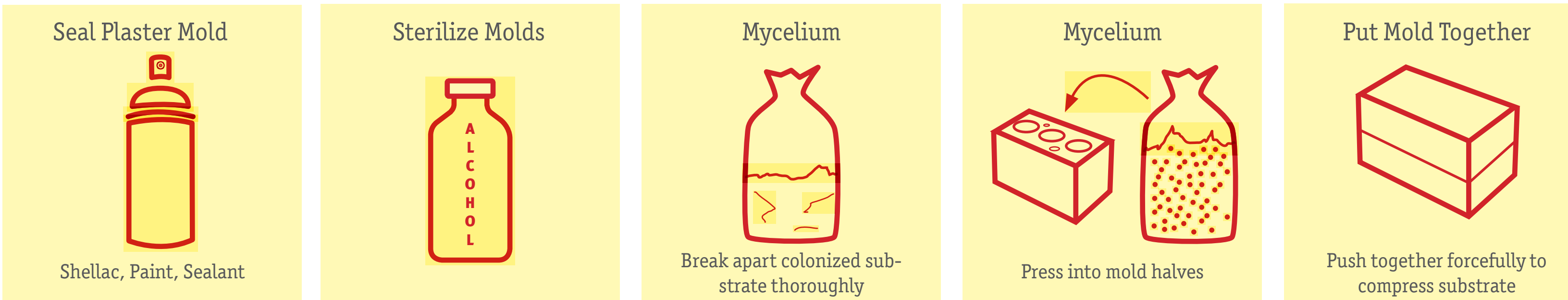
Molding colonized substrate (plaster molds)

It was essential to sterilize everything once again (including the plaster molds, pictured below) before transferring the substrate into the molds. 6 gang molds of simple bowl forms and 2 which had been cast from clay forms based on bowls were made to test moldability and resolution of the material. We put the peroxide-enhanced mycelium mixtures in the shaped molds and the other 6 mixtures in the bowl gang molds, compressing after filling. (See flow chart on next page)

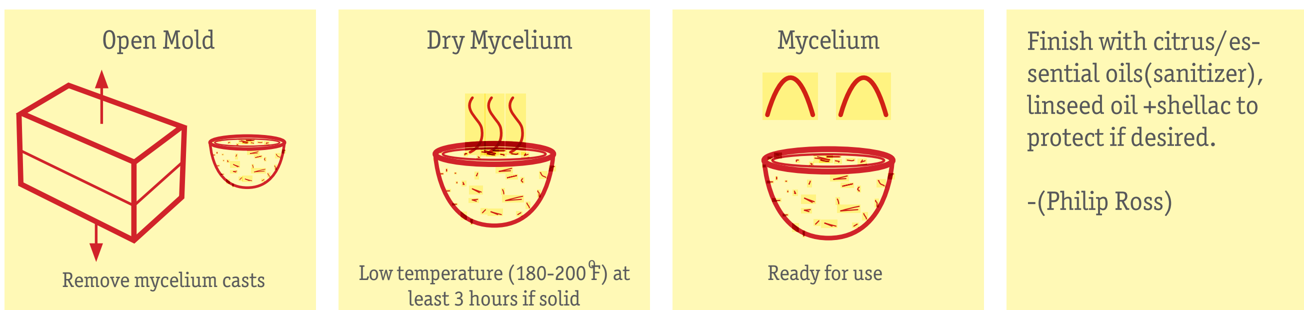
Illustration 18: Our experimental mold to see what kinds of shapes are possible

Illustration 17: Finished gang mold

Molding colonized substrate (flow chart)



Wait roughly 2 weeks for mycelium to grow within mold.



Unmolding and curing final product

Eleven days after molding the mycelium into swatches and the plaster molds, the swatches were ready for curing. Most of them were well colonized, with lots of white mycelium on the surface. They felt firm and a little spongy, like wet foam. The optimal conditions for curing, according to Philip Ross, are baking at 200 degrees Fahrenheit for 3 or more hours, depending on the thickness of the final product. However, as the swatches were thin, in this case it was acceptable to cure them on the roof. It was a hot, sunny, dry day, and the reflective coating on the roof reflected heat on the swatches. Supported by leftover green fencing from above and below, they cured like this for approximately 6 hours (to be on the safe side).

Illustration 19: Curing swatches to test material properties

Illustration 20: Curing swatches to test material properties

Testing

In order to compare the strength of the swatches, a flexural strength test was used. This measures how much a material can be bent without cracking, which is important to know for applications in which the mycelium would need stiffness and flexible strength—for instance, in a chair made entirely of mycelium. The three-point flexural test involves suspending the swatch between two supports and then gradually adding weight to the middle of the swatch (in our case by gradually pouring water into a lightweight bucket hung across the sample). To measure the maximum force the swatch could sustain, we measured the amount of water poured in and then converted to pounds. Flexural strength is independent of the differing widths and thicknesses of the materials tested, which is ideal for these swatches, whose dimensions varied. The flexural strength of a material is given by:

$$\sigma = \frac{3FL}{2bd^2}$$

where F is the force in lbs on the swatch, L is the length between the supports, b is the width of the swatch, and d is the height of the swatch.

Due to the limitations of our measuring equipment, we must look at the strength results critically, especially as the thickness has such a large effect on the result (the thickness of our swatches was not consistent across the swatches nor on individual swatches). Furthermore, the material is not entirely homogeneous, as the mycelium didn't always grow evenly. However, the calculated flexural strength of the swatches is still a good indicator of certain differences. Considered in conjunction with qualitative assessments made of each swatch, it adds to the understanding of which materials are preferable.

These qualitative assessments of properties such as smoothness, level of colonization and coverage, and pliability were essential in fully evaluating and analyzing the swatches. We also photographed each swatch for reference (see Appendices C, D, and E).

Illustration 21: Strength testing setup

Illustration 22: Prepping swatches to test flexural strength

Results

On those samples which were very well colonized, the surface mycelium retained the wrinkles of the bag in which it had grown with high resolution, showing us that complex textures can be rendered with a fairly high level of detail as long as there is enough mycelium at the surface. Increased colonization also correlated positively with increased pliability, which indicates that more mycelium growth can make the material more durable and less subject to cracking.

Comparison of Support Materials

We observed that the mycelium felt less fragile when grown with support materials that had smaller holes, like the screens, burlap, and nylon mesh. Because the holes in the poultry netting, hardware cloth, and green fencing were so large, the mycelium was not supported for large areas and was broke through the holes more easily when handled. However, these swatches did very well in the strength test. This could be largely due to the strength of the support materials themselves, which would relieve strain otherwise transferred to the mycelium. It was often quite difficult to measure the width and thickness of these samples as the crumbling mycelium and poor coverage resulted in non-rectangular shapes.

The poultry netting, hardware cloth, and metal screen (support materials made of metal) tended to have lower mycelium coverage than swatches with other support materials, though they were made with the same original colonized substrate.

The screens and cloth samples did not fare as well in strength tests because these materials had very little stiffness themselves. However, comparatively, the mycelium had a greater strengthening effect on the floppier support materials than it did on the already-strong meshes. Swatches with smaller-pored meshes also did not crumble nearly as much and thus felt sturdier when handled.

Surprisingly, the mycelium tended to grow the most around the edges, on the surface, and on the supports of the poultry netting, hardware cloth, and plastic fencing. We did not expect this, as these places do not have as much substrate and thus would have fewer nutrients for the mycelium to consume. This effect could also be perceptual, though, as it is more difficult to see the mycelium hyphae in the substrate than on the surface (where it can form a tight, white, consistent network unobstructed by sawdust particles).

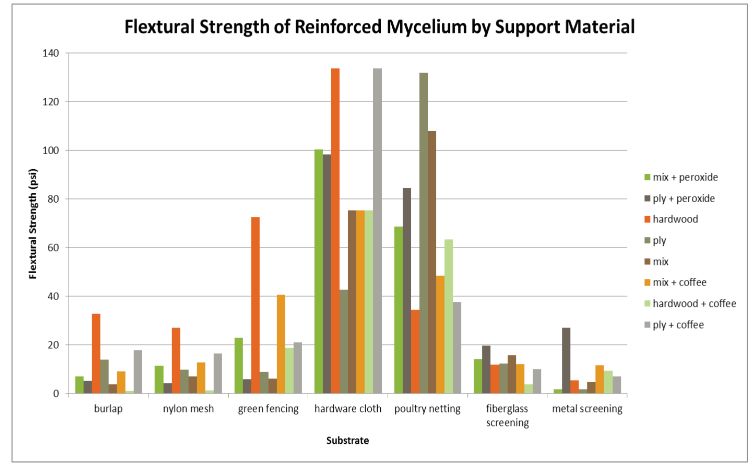


Figure 1: Comparing swatch strength by support material.

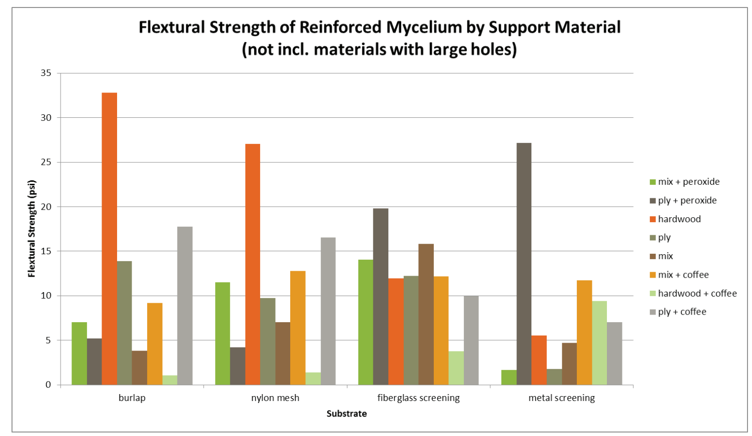


Figure 2: Comparing swatch strength by support material. This graph shows only swatches with burlap, nylon mesh, fiberglass screening, and metal screening so they can be more easily compared.

Comparison of Substrates

Across the substrate conditions, the type of wood in the substrate was much more important in determining flexural strength and surface qualities than the additives (coffee or hydrogen peroxide).

Hardwood shavings without any additives had the highest overall strength across support materials. But, it was unpleasantly rough and crumbly to the touch, so much so that shavings fell off the surface as we ran our fingers across the material. On the other hand, the plywood and mixed substrates felt much smoother, especially when completely colonized and white on the surface. Their strengths were slightly lower, but they were much more cohesive and did not crumble hardly at all.

The addition of coffee increased the strength of both the plywood and mixed sawdust swatches, though it negatively affected the hardwood strength. However, the hardwood with coffee added had greater mycelial growth, which seemed to correlate positively with strength in other substrates. The addition of hydrogen peroxide had little effect on the growth, and these samples had some black spots, indicating contamination by a competing organism. This is exactly the opposite of what we would expect, as peroxide is generally thought to help prevent contamination. There were also a few black spots on the hardwood samples, but other samples were uncontaminated.

Overall, the strongest substrates were hardwood (no additives), mix with coffee, and plywood with coffee. Hardware cloth and poultry netting made the strongest swatches of the support materials, but they are very strong to begin with. Furthermore, these large metal meshes created large holes for the mycelium to crumble through, breaking with gentle handling. The finer support materials made more pliable and sturdy swatches, with the burlap and fiberglass screening giving fairly good strength and surface texture. Plywood had the smoothest surface, as the grains of the substrate were the smallest. Plywood and mixed substrates with coffee grounds grew more mycelium and were slightly stronger than those without, which probably explains their slightly higher strength. Adding hydrogen peroxide did not help the growth of the mycelium, and those swatches with peroxide were actually contaminated. Untreated samples were for the most part uncontaminated.

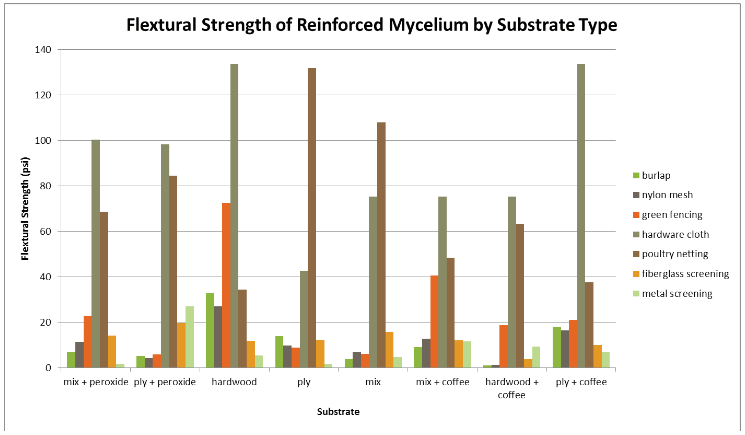


Figure 3: Comparing swatch strength by substrate type.

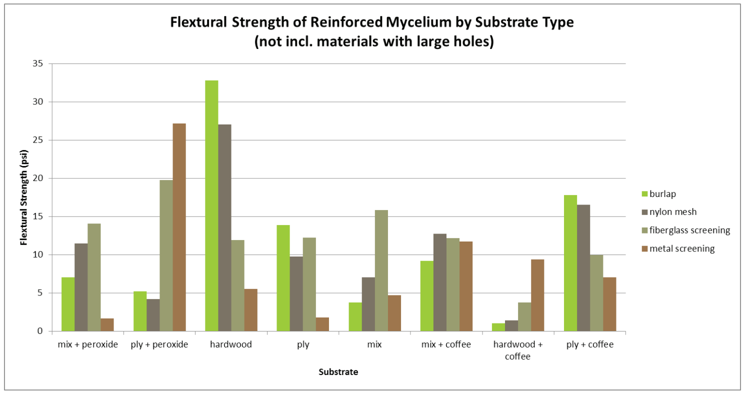


Figure 4: Comparing swatch strength by substrate type. This graph shows only swatches with burlap, nylon mesh, fiberglass screening, and metal screening so they can be more easily compared.

Plaster Molds

The plaster-molded mycelium did not turn out as expected. When we tried to take off the top half of the mold, they cracked through the middle of the substrate rather than pulling cleanly out on the surfaces.

However, there was plentiful mycelium growth along the edges of the molds, where the mycelium had been exposed to air, and between flat faces of the mold. One mold was even pushed apart by the mycelium, separating the halves. Because the mycelium seemed to be positively responding to air and space in the swatch tests, growing near the edges and surfaces, we decided to experiment with leaving a mold open. The substrate held together enough to keep its form when the mold was opened, though leaving it open seemed to have little effect on growth.

Another reason the mycelium did not unmold cleanly could be that they weren't prepared properly. Though sealing with wax is a common way to make a moisture barrier, it could have been too rough (we painted it on the mold) and stuck to the mycelium, making it more difficult to remove from the mold. We noticed that it was easier to peel the wax from the plaster than the mycelium from the wax, so in future studies we would modify our procedure to prepare the molds with murphy's oil or something similarly slick which also wouldn't interfere with growth. Furthermore, plaster molds take a long time to dry, which we were unable to spare in our process, so the mycelium grew in "wet" molds (they were still solid and cured, but there was a lot of water remaning in the plaster which had not dried out). Ecovative has been using vacuum formed plastic molds to mold their mycelium, which would also be smoother and more flexible to aid in unmolding. This was cost prohibitive in the current experiment but would be valuable to investigate further.

Illustration 23:The molds, one propped up by the mass of mycelium growing at the surface

Illustration 24: Opening a mold. The mycelium cracked and did not slide cleanly from the mold

Discussion

The current study used Reishi spawn, as it seemed from current research that it would produce a stronger and stiffer mycelium than Oyster spawn, which is also used by some currently experimenting in this field. Oyster mushrooms are known to grow more quickly than Reishi, though it is not clear if this extends to their respective mycelium growth rates. If this is the case, Oyster spawn could be a better choice in the mass production of mycelium based products providing it is strong enough for the desired application. In future studies, growth times and strengths of different varieties of fungi should be studied and reported.

The addition of coffee grounds helped the samples' strengths in the case of plywood and mixed substrate. This is likely due to the nitrogen in the coffee, an essential nutrient which probably helped the mycelium grow more quickly and fully. Mycelium binds the substrate together, so increased mycelium growth lends strength to the samples. These samples showed both increased growth and greater strength, which agrees with this theory. It is unclear why coffee grounds had such a negative effect on the strength of the hardwood, though it did increase mycelial growth.

It was unexpected that the samples with added hydrogen peroxide were actually contaminated, while those without were for the large part completely uncontaminated (except for a couple of spots on one or two hardwood swatches). We would expect the peroxide, which can reduce the risk of contamination by killing small amounts of competing organisms present in the substrate, to help the mycelium grow by decreasing competition. Perhaps it helped prevent contamination at the start, but the growing mycelium did not develop resistance, and then became contaminated when the peroxide ran out. Regardless of the explanation, adding peroxide does not seem to be helpful, especially since we thoroughly pasteurized the substrate before inoculating with spawn and took precautions to reduce contamination when working with the mycelium. The swatches revealed an interesting growth pattern near the metal supports of chicken wire and hardware cloth, which was initially attributed to minerals in the metal which may have been advantageous to growth. However, it also displayed this behavior around the solid, large-pored mesh of the plastic fence, which is not metal, and it did not show this effect on the metal window screen. Furthermore, the metal support materials often showed the least overall mycelial growth. From observing our swatches, it seems there may be a physical reason for this growth pattern. For instance, could the fungi be seeking the open air to fruit? It also preferred to grow near the edges of the bags and the surface of the swatches, which supports the theory that it seeks space or air even when that means extending beyond the substrate.

This "pure" mycelium (without substrate) which grew at the edges of the swatches and between the flat faces of the molds was also an unexpected discovery. As there were only small pieces of this material, we could not test its strength. However, it was soft and pleasant to the touch and especially smooth. At about 1/8 in thick, was very pliable but felt strong under tension and did not crack when bent (we were able to rip it by hand, but only with intentional effort). It was flexible like neoprene or sheet foam. Further investigation is necessary to determine exactly the properties of this material, ways to produce pure mycelium, and potential applications.

The swatches we produced, by contrast, were pretty brittle, especially with a large-pored support material. From observation, however, the material's compressive strength seems high. Companies currently using mycelium material often use it in places where compressive strength is important but tensile, flexural, and torsional strength are not, such as in packaging material and insulation (Ecovative). When force is applied to bend or twist the swatches, they crack fairly easily.

To further test moldability of mycelium materials, it would be advisable to use thin plastic or other flexible molds. Drilling air holes in the molds could also aid growth, as mycelium needs oxygen.

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List of Figures and Illustrations

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Figures

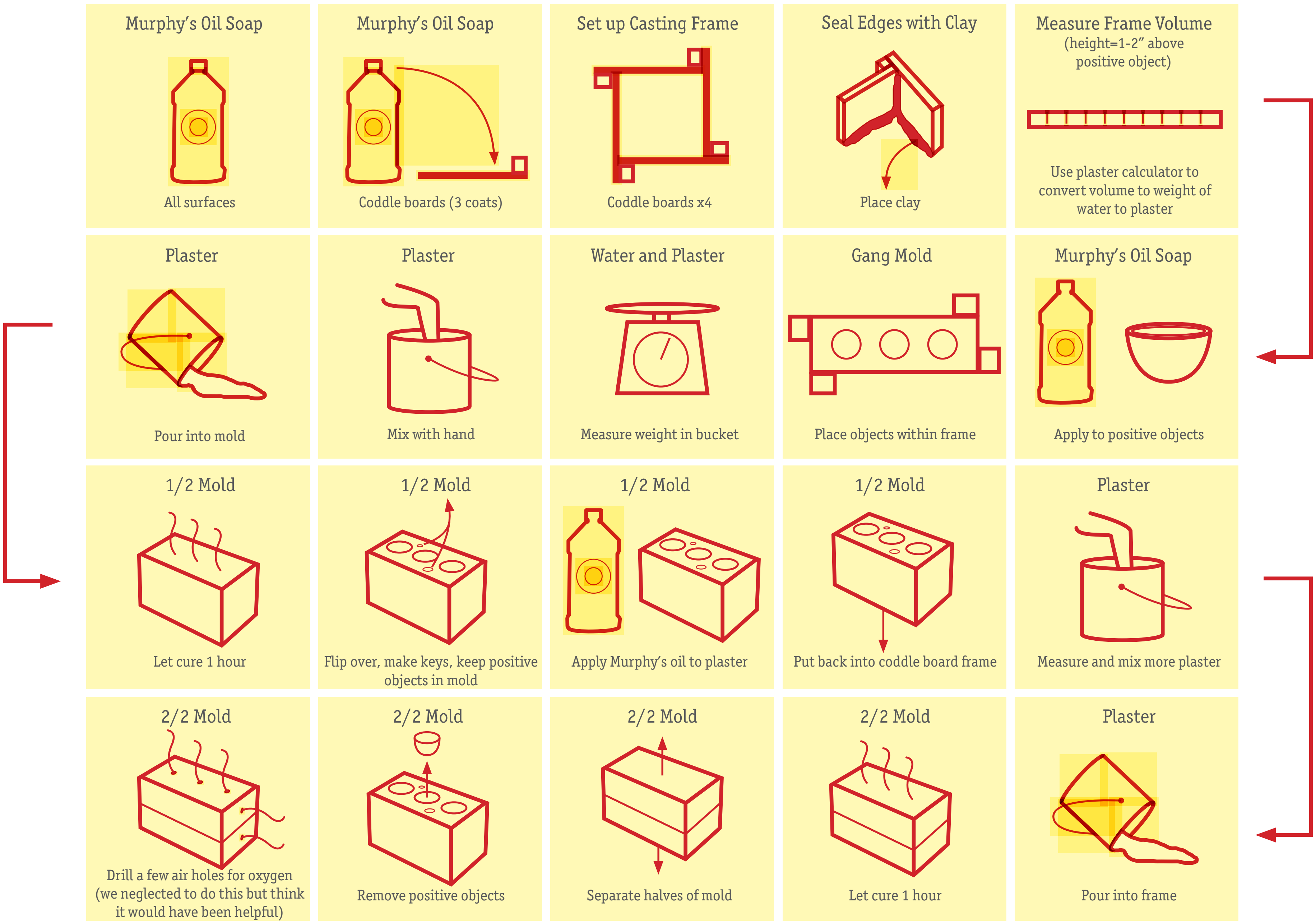
Appendix A: Materials

Name	Store	Price	Date bought
Microcrystalline Wax (1 lb)	Blick	$15.29	7/2/2014
Throwing Clay (50 lb)	Blick	$11.78	7/2/2014
Plaster (50 lb)	Lillstreet Art Center	$25.00	7/2/2014
Fiberglass Screen	Home Depot	$6.95	7/2/2014
Hardware Cloth	Home Depot	$4.38	7/2/2014
Poultry Netting	Home Depot	$4.38	7/2/2014
Green Multipurpose Fence	Home Depot	$7.94	7/2/2014
Window Screening	Crafty Beaver	$5	6/30/2014
Paint Strainer (polyester mesh)	Crafty Beaver	$2	6/30/2014
Murphy's Oil	Crafty Beaver	$2	6/30/2014
Paintbrush	Crafty Beaver	$1	6/30/2014
Scale	Target	$8.73	7/9/2014
Putty Knife	Crafty Beaver	$3.59	7/9/2014
2 quart mixing containers	Crafty Beaver	$5.58	7/9/2014
Sponge	Crafty Beaver	$2.99	7/9/2014
Reishi Spawn	Mushroom People (on-line distributor)	$19.00	6/26/2014
Bowls (to mold)	Thrift store	$6.45	6/30/2014
Total		**$132.06**	

Other materials we already had
Sawdust
Scrap wood for cottle boards
Water
Clamps
2 5-gallon buckets
A double boiler (or equivalent)

Appendix B: Making plaster molds

To make the plaster molds, use pottery plaster, a finer plaster with more strength than the widely used plaster of paris.



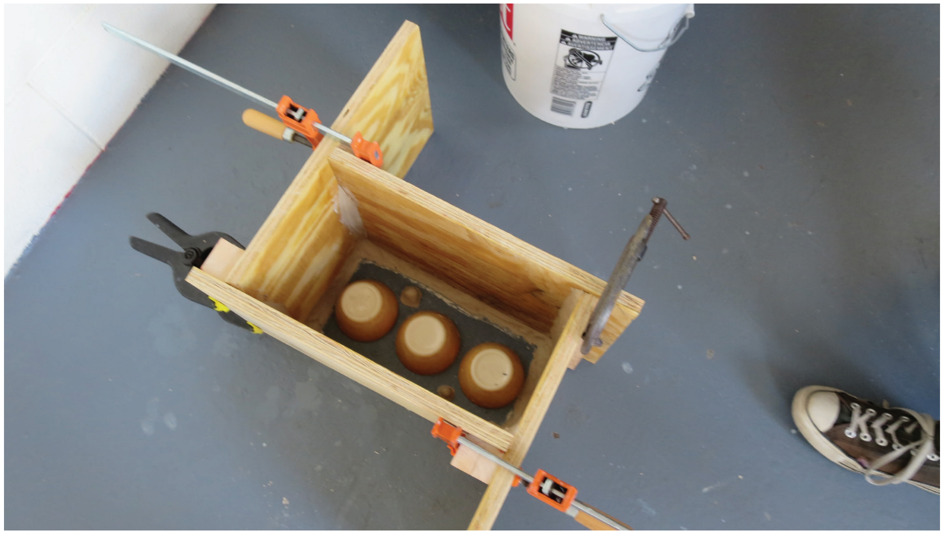


Illustration 25: Frame and positives ready for plaster

Illustration 26: Pouring plaster

Illustration 27: Hand mixing plaster

Illustration 28: Preparing to pour second half of mold

Appendix C: Strength testing data

Substrate	*Reinforcing Material*	*Length between clamps (in)*	*Width of sample (in)*	*Height of sample (in)*	*Force at which swatch broke (lb)*	*Flexural Strength (psi)*
mix + peroxide	burlap	3.75	5	0.38	0.88	7.04
mix + peroxide	nylon mesh	3.75	4.5	0.22	0.44	11.49
mix + peroxide	green fencing	3.75	4.5	0.22	0.88	22.99
mix + peroxide	hardware cloth	3.75	3.75	0.25	4.18	100.32
mix + peroxide	poultry netting	3	3	0.25	2.86	68.64
mix + peroxide	fiberglass screening	3	4	0.19	0.44	14.08
mix + peroxide	metal screening	3	3	0.31	0.11	1.69
ply + peroxide	burlap	3	4.38	0.31	0.50	5.21
ply + peroxide	nylon mesh	3	3.75	0.38	0.50	4.22
ply + peroxide	green fencing	3	4.63	0.31	0.61	6.03
ply + peroxide	hardware cloth	3	4	0.22	4.18	98.27
ply + peroxide	poultry netting	3	3	0.25	3.52	84.48
ply + peroxide	fiberglass screening	3	4	0.25	1.1	19.8
ply + peroxide	metal screening	3	3.5	0.13	0.33	27.15
hardwood	burlap	3	4.25	0.13	0.48	32.80
hardwood	nylon mesh	3	4.5	0.16	0.66	27.03
hardwood	green fencing	3	4.5	0.19	2.55	72.59
hardwood	hardware cloth	3	4	0.19	4.18	133.76
hardwood	poultry netting	3	5	0.31	3.74	34.47
hardwood	fiberglass screening	3	4.5	0.22	0.57	11.95
hardwood	metal screening	3	3.75	0.22	0.22	5.52
ply	burlap	3	4.5	0.28	1.1	13.91
ply	nylon mesh	3	3.75	0.19	0.29	9.76
ply	green fencing	3	4.25	0.28	0.66	8.83
ply	hardware cloth	3	4.5	0.31	4.18	42.80
ply	poultry netting	3	2.5	0.19	2.57	131.79
ply	fiberglass screening	3	3.75	0.25	0.64	12.25
ply	metal screening	3	3.5	0.28	0.11	1.79
mix	burlap	3	4	0.31	0.33	3.80

mix	nylon mesh	3	4	0.19	0.22	7.04

Substrate	*Reinforcing Material*	*Length between clamps (in)*	*Width of sample (in)*	*Height of sample (in)*	*Force at which swatch broke (lb)*	*Flexural Strength (psi)*
mix	green fencing	3	4.5	0.34	0.72	6.05
mix	hardware cloth	3	4	0.25	4.18	75.24
mix	poultry netting	3	3	0.19	2.53	107.95
mix	fiberglass screening	3	4	0.13	0.22	15.84
mix	metal screening	3	3	0.19	0.11	4.69
mix + coffee	burlap	3	3.88	0.34	0.94	9.19
mix + coffee	nylon mesh	3	3.38	0.31	0.94	12.77
mix + coffee	green fencing	3	4.5	0.16	0.99	40.55
mix + coffee	hardware cloth	3	4	0.25	4.18	75.24
mix + coffee	poultry netting	3	4.25	0.25	2.86	48.45
mix + coffee	fiberglass screening	3	4.25	0.22	0.55	12.17
mix + coffee	metal screening	3	3	0.19	0.28	11.73
hardwood + coffee	burlap	3	4	0.22	0.04	1.03
hardwood + coffee	nylon mesh	3	4.5	0.13	0.02	1.41
hardwood + coffee	green fencing	3	4.5	0.19	0.66	18.77
hardwood + coffee	hardware cloth	3	4	0.25	4.18	75.24
hardwood + coffee	poultry netting	3	4.25	0.25	3.74	63.36
hardwood + coffee	fiberglass screening	3	3.75	0.19	0.11	3.75
hardwood + coffee	metal screening	3	3	0.19	0.22	9.39
ply + coffee	burlap	3	4.75	0.28	1.49	17.79
ply + coffee	nylon mesh	3	4.25	0.19	0.55	16.56
ply + coffee	green fencing	3	4	0.19	0.66	21.12
ply + coffee	hardware cloth	3	4	0.19	4.18	133.76
ply + coffee	poultry netting	3	3.5	0.31	2.86	37.65
ply + coffee	fiberglass screening	3	4.25	0.19	0.33	9.94
ply + coffee	metal screening	3	3	0.19	0.17	7.04
none	green fencing	3	4.5	0.06	0.88	225.28
none	hardware cloth	3	5	0.05	4.18	1712.13
none	poultry netting	3	2.75	0.05	3.74	2785.28
none	metal screening	3	3	0.03	0.06	84.48

Appendix D: Qualitative observations of swatches

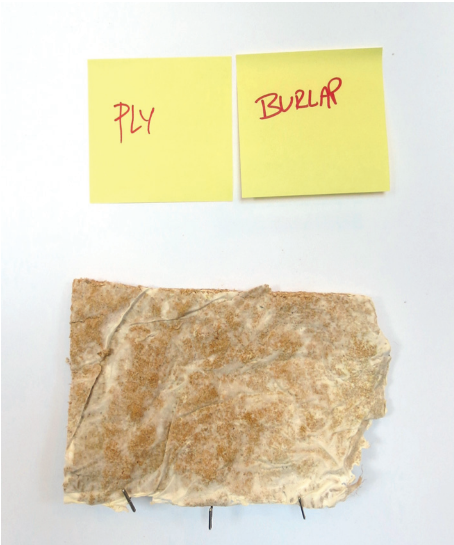
Substrate	*Reinforcing Material*	*Mycelial growth*	*Total coverage of material*	*Surface texture*	*Other notes*	*Pliability*
mix + peroxide	burlap	really white, even, homogeneous.	yes! plenty	Can see some burlap through, fairly smooth, small bumpiness	large, sturdy swatch	quite bendy
mix + peroxide	nylon mesh	very white, patches of no brown	not quite, but still solid material. Can see where there wasn't coverage on one side of fabric	smooth, can see fabric through (not quite enough coverage), picked up texture of plastic bag folds. Some black mold?	very similar to burlap	bendy
mix + peroxide	green fencing	very white, patches of no brown	good. even though the plastic bends	got plastic bag texture in mycelium, pretty smooth with small bumps	not adhering to plastic very well, peels off of support	oblique easier than straight, quite pliable
mix + peroxide	hardware cloth	looks like dirt. hardly any coverage, crumbles in our hands	not really, major holes. minimal growth	sawdusty, crumbly, bumpy, no white smooth parts	there is mycelium growing ON the metal, even though there's hardly any at the surface. did not fracture because hardware cloth is too strong.	as pliable as the support material
mix + peroxide	poultry netting	blackish spots, a few white areas but nothing really at the surface. signs of rust.	not at all	awful, very fragile feeling. crumbles at the touch	mycelium does seem to stick to the metal, even though there's hardly any coverage.	as pliable as the support material
mix + peroxide	fiberglass screening	lots	not quite, but still solid material. Can see where there wasn't coverage on one side of fabric	smooth, nice white patches feel like styrofoam	seems strong	pretty pliable.
mix + peroxide	metal screening	a lot of good growth, but tends to be beneath a layer of sawdust	not really, major holes	smooth where white, rough and crumbly where there's no mycelium. feels fragile	really lumpy application of substrate, not sticking to screen	fissures along surface
ply + peroxide	burlap	very white, patches of no brown	yes, lots of even coverage	pretty smooth, shows bag wrinkles		yes, less where thicker
ply + peroxide	nylon mesh	very white, patches of no brown	not even...a lot on one side, hardly any on the other. but still solid	cracking already occuring, but otherwise pretty smooth	very thick...one spot of blacker mold	pretty pliable.
ply + peroxide	green fencing	yes, especially near green part	yes, though was bent so can see fence on one side	pretty smooth, shows bag wrinkles	some cracking, one blacker spot,	cracking a little
ply + peroxide	hardware cloth	some spots of really white but otherwise crumbly and sawdusty	not very good, some holes	crappy, crumbly	not adhering to metal, just to self/on other side. heavy growth around rusting parts	less pliable than support material

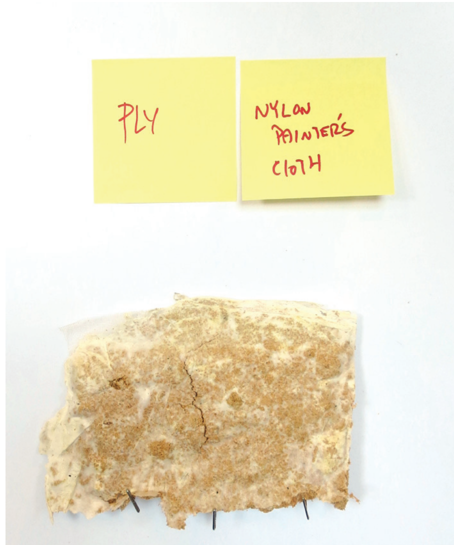
ply + peroxide	poultry netting	some patches good, especially around rusty wire	awful...50%	crappy, crumbly	chunks fell off in our hands, triangular	less pliable than support material. stiff, brittle
ply + peroxide	fiberglass screening	nice, lots of white	yes, but a little less around the edges	pretty smooth, shows bag wrinkles	feels foamy where just white!	slightly pliable, a bit of cracking
ply + peroxide	metal screening	nice, lots of white	good, complete	lumpy, but smooth	a little yellowing.	no, brittle
hardwood	burlap	lots of white	yes	feels rougher than mix or ply	feels a bit flimsier	fractures a bit when bent
hardwood	nylon mesh	a fair amount of white, but not complete	yes	rough but holding together	cracks, one black spot	not that flexible, cracking
hardwood	green fencing	a fair amount of white, but not complete	yes	rough even where there's a lot of white because substrate particles are large		can twist but more brittle than others
hardwood	hardware cloth	hardly any	not complete, but good coverage on part	rough and a bit crumbly	black spot	mycelium would break before the wire even bent
hardwood	poultry netting	some...	good	like particleboard, rough, a bit crumbly	black spot	mycelium would break before the wire even bent
hardwood	fiberglass screening	lots	some spots, but it all holds together	rough and lumpy	seems strong under compression but not tension	pretty pliable.
hardwood	metal screening	40%	some spots but holds together	rough, a bit crumbly	not square	cracks
ply	burlap	very!	yes	smoothest, shows bag texture really well	some cracking	pretty pliable.
ply	nylon mesh	lots	yes	smoothest, shows bag texture really well	one black spot around a staple (contaminated?)	fairly pliable but cracking
ply	green fencing	lots, especially around green parts	yes	quite smooth	sticking to green stuff very well	cracking
ply	hardware cloth	some, mostly around rusty parts	mostly, some spots where not covered well	very crumbly	more compacted than the mix	as pliable as the support material
ply	poultry netting	half lots, half hardly any	pretty good, for chicken wire	crumbly except smooth where white	not square	as pliable as the support material

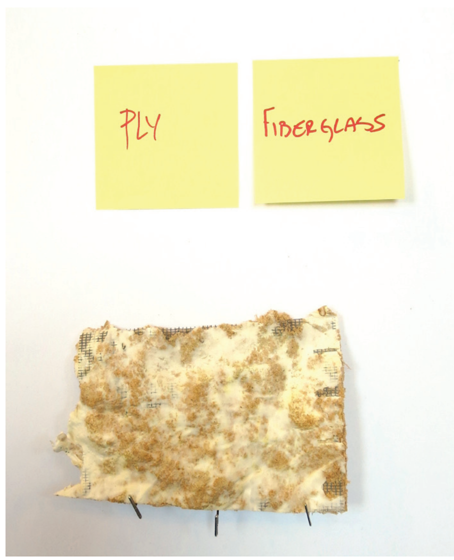
ply	fiberglass screening	a TON! more in the cavities	not really good, but so much mycelium that it doesn't matter	super smooth	sooooo nice!	good...quite pliable com-paratively
ply	metal screening	more on one half than the other	yes	partially crumbly, partially smooth		cracks, crumbles
mix	burlap	great, really well colonized	yes	fairly rough but cohesive, fine		pretty pliable.
mix	nylon mesh	lots of white	yes	a bit rough, run a finger across it and some comes off		pretty pliable.
mix	green fencing	lots of white esp where green	yes	a bit rough, run a finger across it and some comes off	mycelium likes to grow around green mesh	a little pliable
mix	hardware cloth	only on one side	yes	really crumbly, less so where there's more mycelium		as pliable as the support material
mix	poultry netting	some white	yes but crumbly	really crumbly, less so where there's more mycelium	pops through the holes	as pliable as the support material
mix	fiberglass screening	great, really well colonized	yes	rough but cohesive	very thin!	quite pliable
mix	metal screening	on one half, bad on other	not quite enough	really crumbly, less so where there's more mycelium	pretty thin	pretty pliable.
mix + coffee	burlap	lots. yellow from cof-fee	yes	nice smooth texture, a bit lumpy. cohesive		a little pliable
mix + coffee	nylon mesh	lots, some yellow spots	yes	smooth, shows bag marks, cohe-sive		a little pliable
mix + coffee	green fencing	good, even. can still see sawdust. prefers around green stuff	yes	quite smooth, a few tiny crumbles		pretty pliable.
mix + coffee	hardware cloth	not much, some parts have more but still mostly crumbly	yes	crumbles. not at all cohesive	rusty around metal	as pliable as the support material
mix + coffee	poultry netting	a fair amount of growth!!	yes	a bit rough, not too crumbly but not smooth	does not stick to metal, wants to break off.	brittle and fragile
mix + coffee	fiberglass screening	yes but also a lot of yellow	yes	a little bumpy, but shows bag textures	fairly lumpy	a little, cracks
mix + coffee	metal screening	pretty good, a fair am-out of sawdust though, especially in middle	yes	pretty smooth, shows bag wrinkles	so much better than most of our metal screen samples	quite where thin

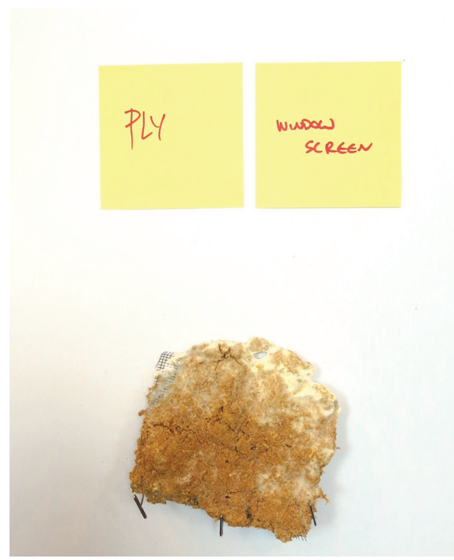
hardwood + coffee	burlap	some white, maybe 30%	yes	awful, very fragile feeling	hardly any growth, just cracking everywhere	na
hardwood + coffee	nylon mesh	a fair amount of growth!!	sort of, pretty much	rough and crumbly	no growth on spots where there's just mesh, black spots	na
hardwood + coffee	green fencing	a fair amount of growth!!	yes	rough but sort of cohesive	not that much growth on green plastic. less dense than other woods	na
hardwood + coffee	hardware cloth	hardly any	no	extremely crumbly, lumpy, awful	blech	na
hardwood + coffee	poultry netting	actually a lot compara-tively!	yes	crumbly, not cohesive	sticks together surprisingly well but is so fragile	na
hardwood + coffee	fiberglass screening	lots	not good	quite rough, crumbly	warped the screen where it grew!	na
hardwood + coffee	metal screening	a lot of growth	so spotty. laughable	still crumbly and not cohesive	just so little coverage it's hard to judge	na
ply + coffee	burlap	so much growth, white and brown spots. much more substrate on top side than the other	yes, plenty	very smooth	what is this weird brown and yellow stuff?	pretty rigid
ply + coffee	nylon mesh	so so much. com-pletely covered (again, more on top side than the other	yes	very smooth	more brown and yellow sploches	a little flexible
ply + coffee	green fencing	so so much. com-pletely covered (again, more on top side than the other	yes	very smooth--silky, even	more growth along creases	fairly flexible
ply + coffee	hardware cloth	not that much, some	sort of, uneven	crumbly	easily pushes through holes in support	as pliable as the support material
ply + coffee	poultry netting	pretty good, more on one side than the other	uneven but concentrated evenly in one area	fragile, crumbly	breaks apart easily	as pliable as the support material
ply + coffee	fiberglass screening	a lot! again, more on top than bottom. some yellow	yes	smooth	yellow but no brown in places	not very except at thin parts
ply + coffee	metal screening	much more than other screen swatches! more on top than bottom	yes, lots of even coverage	smooth		brittle, crack-ing.

Appendix E: Swatch photographs

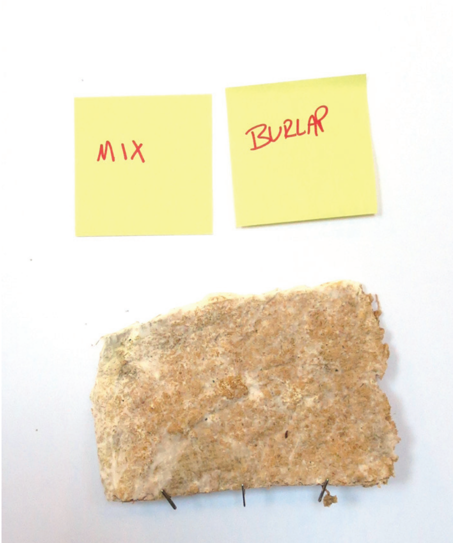








Plywood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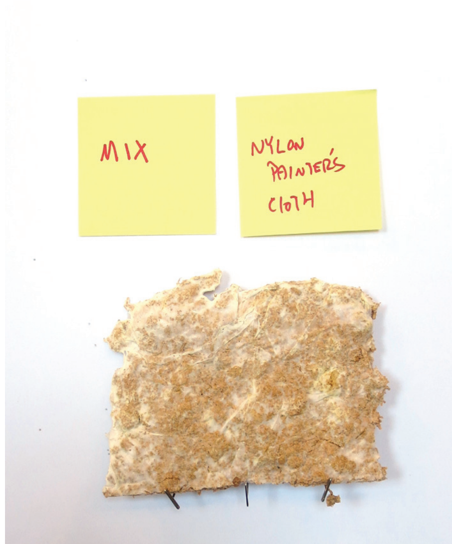
BURLAP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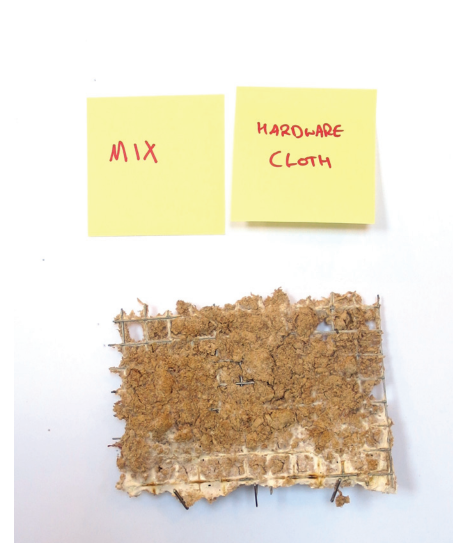
NYLON PAINTER'S CLOTH


MIX
GREEN FENCE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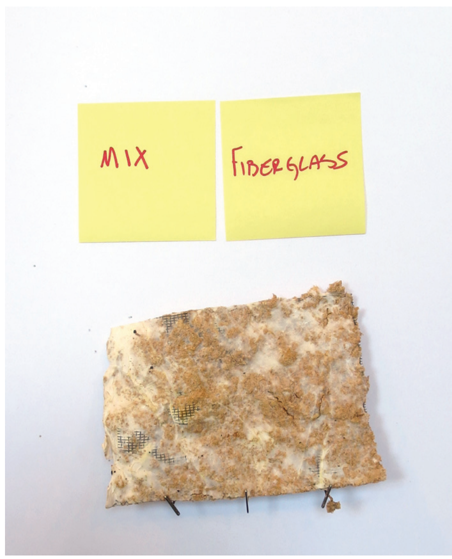
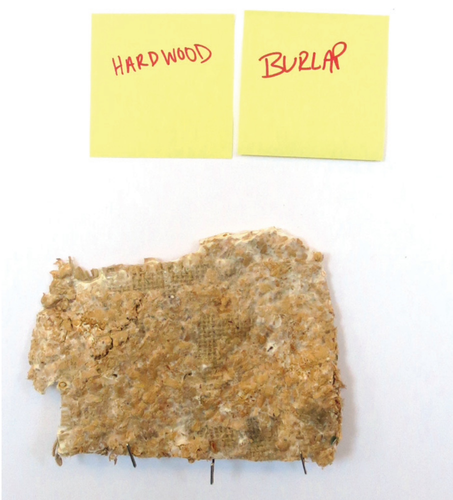
HARDWARE CLOTH


MIX
POULTRY NETTING


MIX
FIBERGLASS


MIX
SCREEN

Mix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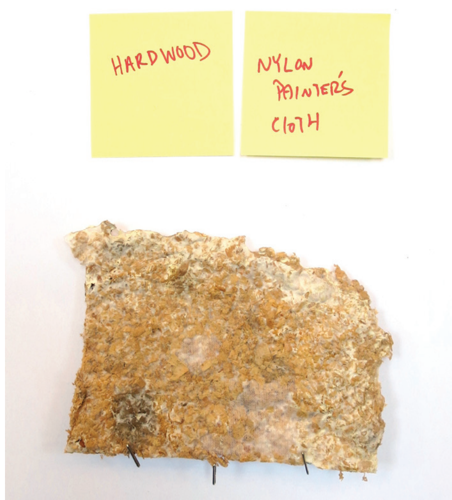
BURLAP

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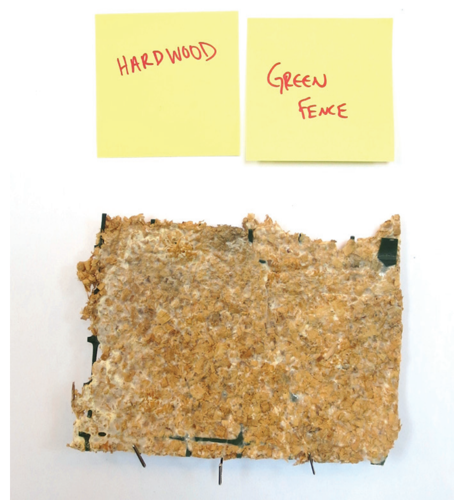
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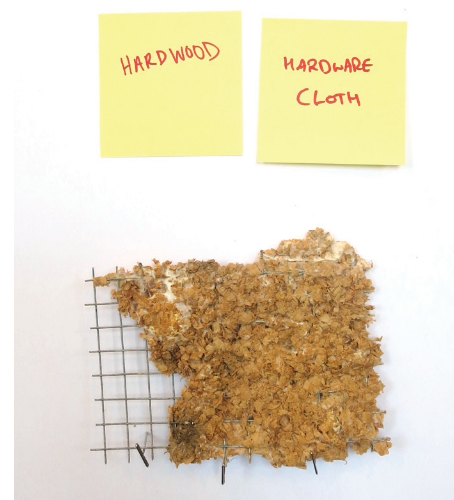
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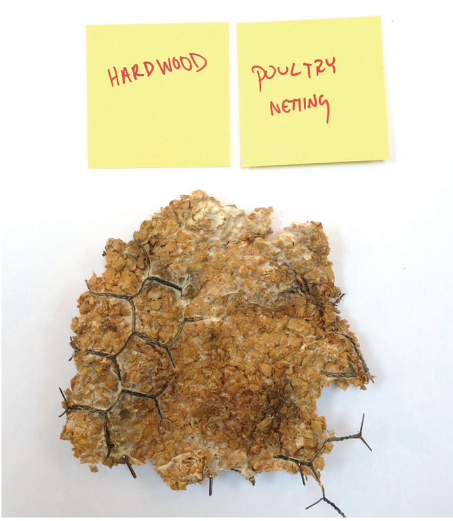
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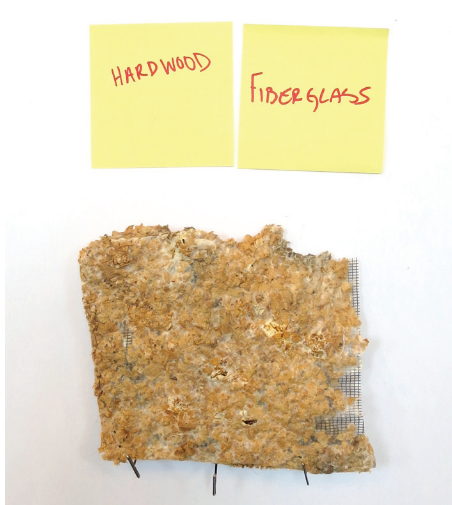
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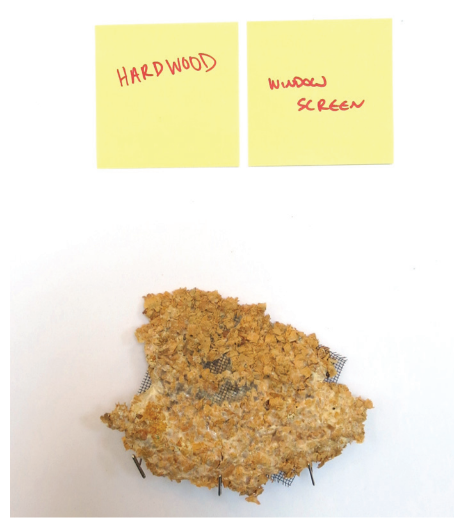
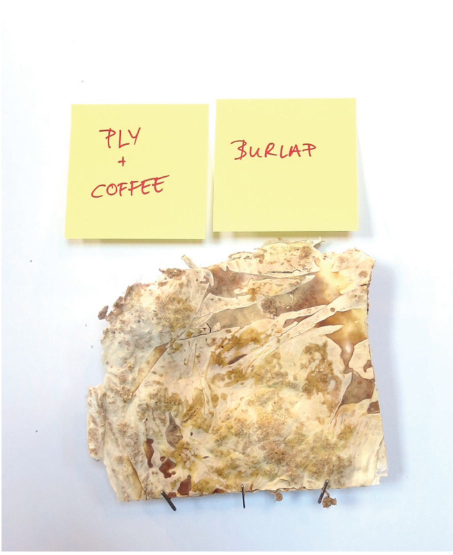
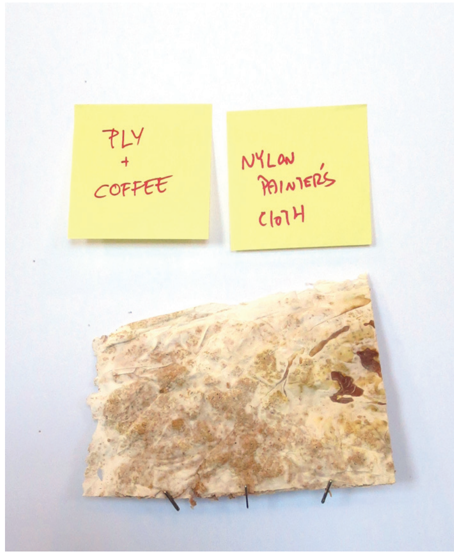
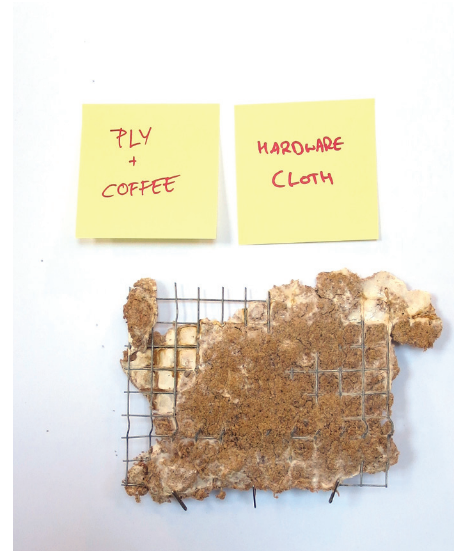
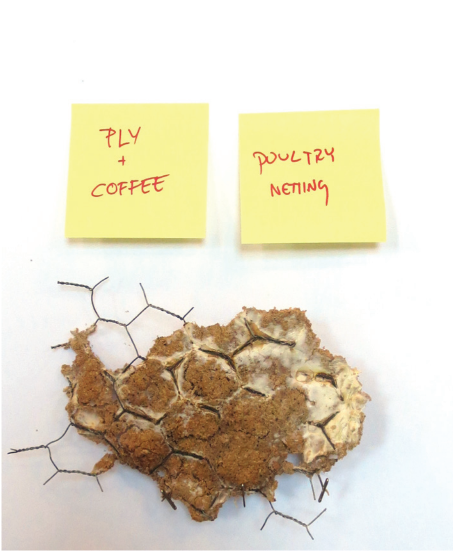
FIBERGLASS

HARDWOOD
WINDOW SCREEN

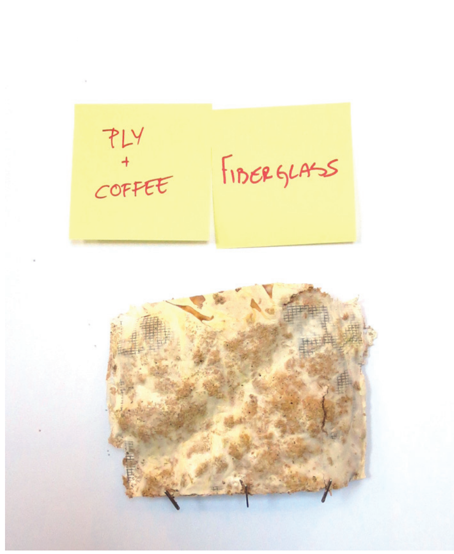
Hardwood

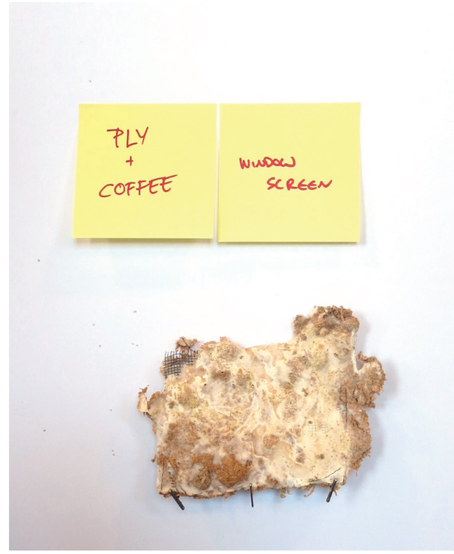




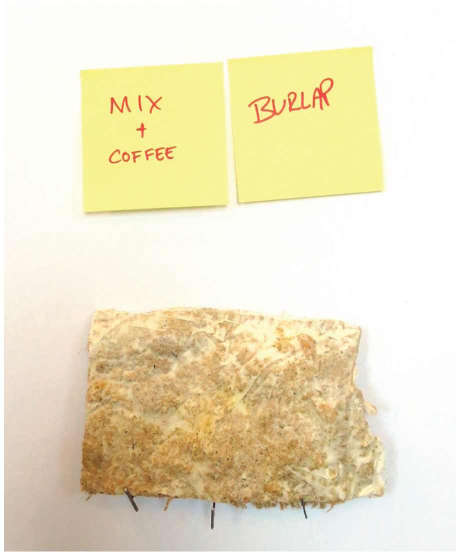






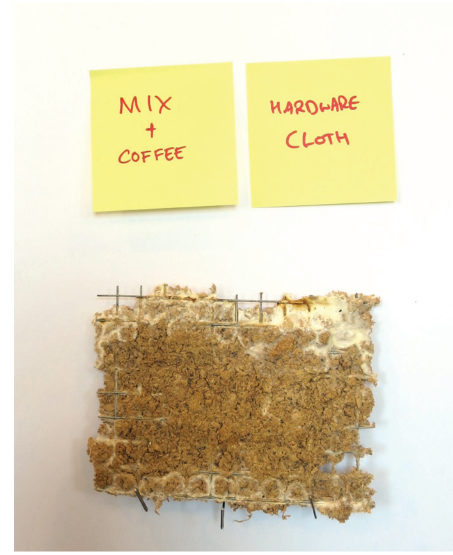


Plywood + Coffee

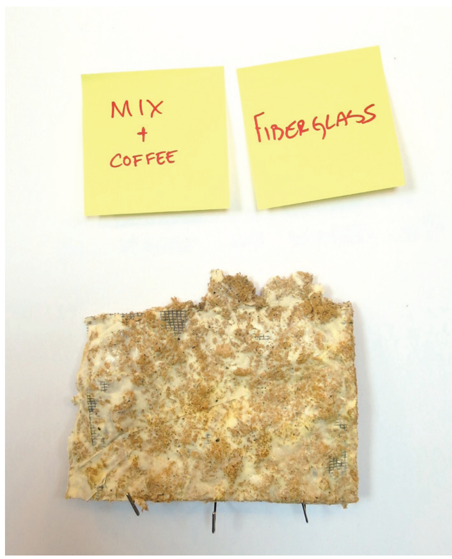

MIX + COFFEE
BURLAP


MIX + COFFEE
NYLON PAINTER'S CLOTH


MIX + COFFEE
GREEN FENCE

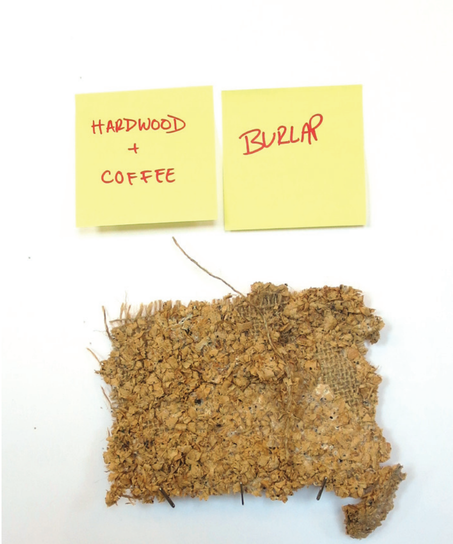

MIX + COFFEE
HARDWARE CLOTH

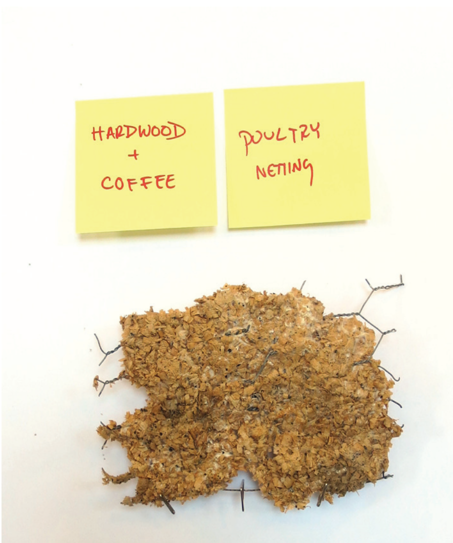

MIX + COFFEE
POULTRY NETTING


MIX + COFFEE
FIBERGLASS

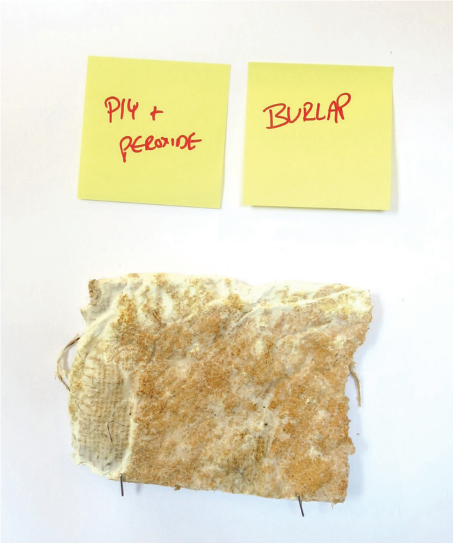

MIX + COFFEE
WINDOW SCREEN

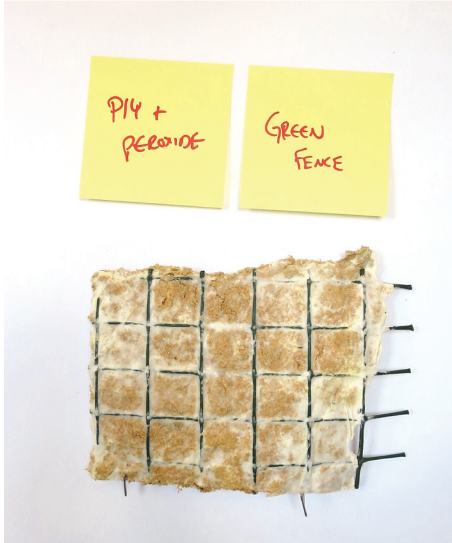
Mix + Coffee

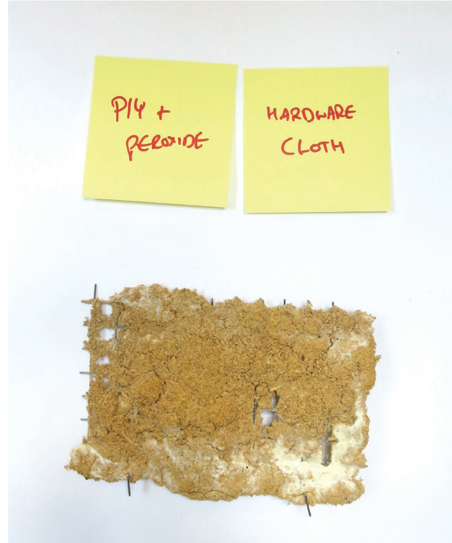


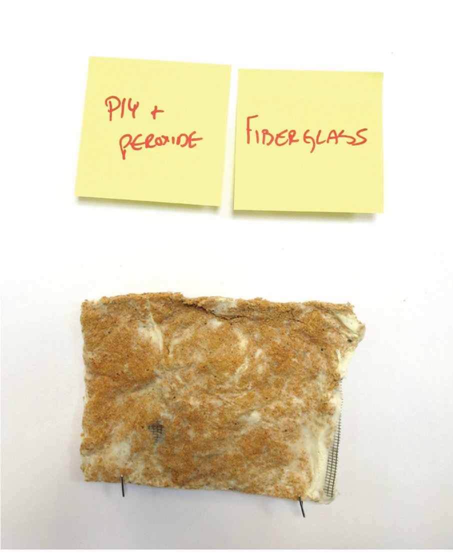


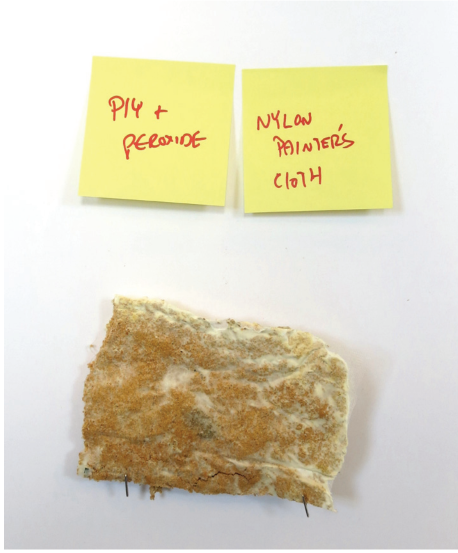
Hardwood + Coffee

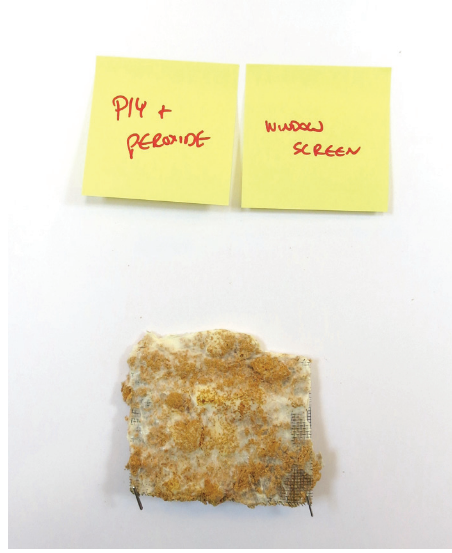




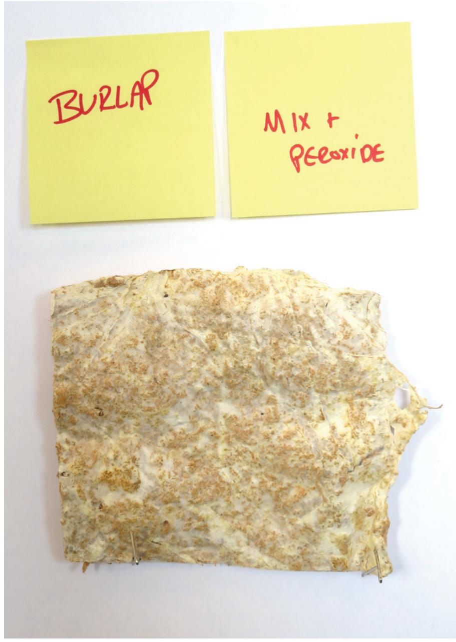


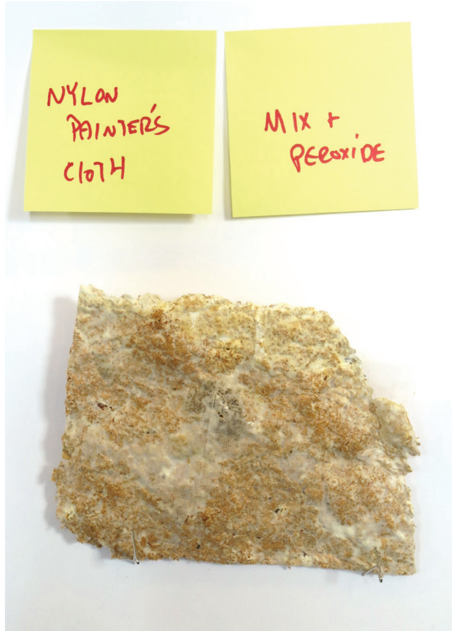


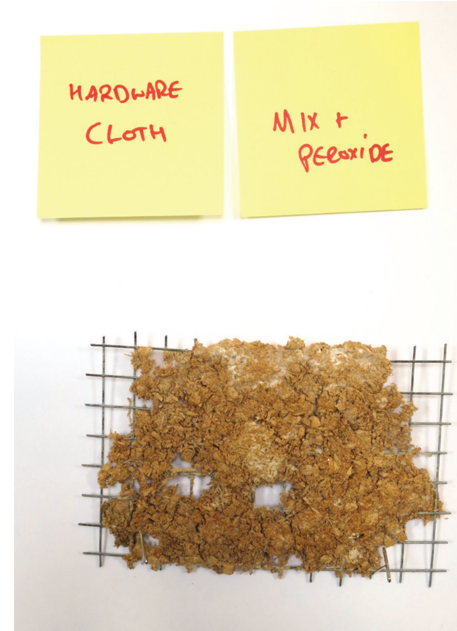


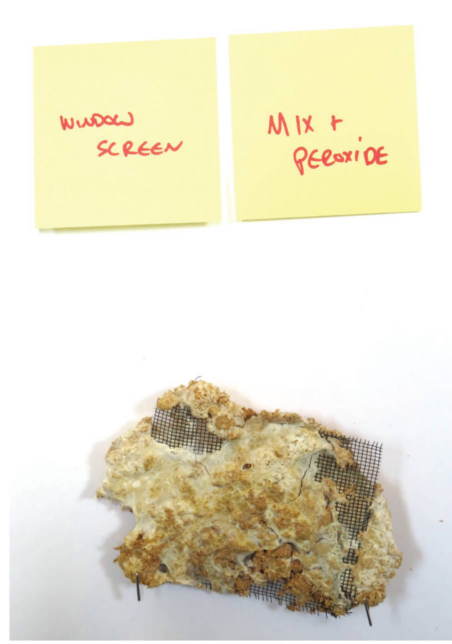


Plywood + Hydrogen Peroxide









Mix + Hydrogen Peroxide